Positive and negative sequence currents optimization to improve voltages during unbalanced faults

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***Abstract*—Grid faults constitute a series of unfortunate events that compromise power systems. With the increasing integration of renewables, the currents injected by power electronic converters are controllable, but at the same time, they have to be limited so as not to damage its semiconductors. This poses the challenge to determine the combination of currents which improves the most the voltages at the point of common coupling. In this paper, such issue is approached from an optimization perspective. Solving the optimization problem allows to compare its solutions with respect to the ones obtained by following the grid code control laws. Two fundamental scenarios are presented: one with a single converter, and another with two converters. Several parameters are varied for all kinds of faults to spot the changes on the currents, such as the severity of the fault, the distance of a hypothetical submarine cable, and the resistive/inductive ratio of the impedances. Overall the results indicate that injecting only reactive power is not always the preferable choice. While grid codes are not optimal, they can be regarded as near-optimal decision rules.**

***Index Terms*—Voltage imbalance, Unbalanced fault, Grid code, VSC current saturation, Positive sequence voltage maximization, Negative sequence voltage minimization**

I. Introduction

The rise in renewable energies has carried along with it the inclusion of Voltage Source Converters (VSC) as a means of coupling energetic resources to the grid while providing controllability [1]–[3]. Adopting such power electronics equipment has induced a progressive shrinkage on synchronous generators' influence in power systems. While synchronous generators suffer an increase in current during faults, which causes protective relays to trigger, the issue is much more prominent in power-electronics-based grids as spikes in current are likely to damage the Isolated-Gate Bipolar Transistors (IGBT) found in VSC [4]. Indeed, current (and also voltage) limiations cause VSC to behave differently. They reach what is called a saturated state. Many equilibrium points may arise as a result of that, specially in grids formed by multiple converters operating in critical conditions. The solution to such systems is also likely to become an arduous task to compute, as saturation states are defined by non-linear equations, or in more detail, by piecewise functions.

Not only currents have to be constrained to not exceed the limitations, but they also have to collaborate on improving the voltages. This becomes specially visible when looking at the requirements imposed by Transmission System Operators (TSO) in its grid codes [5], [6]. Although this was not the case years ago, when wind power supposed a small percentage of the elctricity mix, nowadays wind power plants have to control active and reactive power so as to offer frequency support and voltage support respectively [7]. Besides, they have to transiently support the faults. The latter aspect is often referred to as low voltage ride through (LVRT) [8], [9]. The traditional approach to raise the voltage at the point of common coupling is to inject reactive power proportionally to the severity of the fault [7], [10]. During the analysis of faults, it is often the case that voltages are decomposed into positive, negative and zero sequence by means of the Fortescue's transformation [11]. By doing so, the study of the fault is expected to be simplified, and in addition to that, some intuition can be build from inspecting the positive and negative sequence voltages. A concerning unbalanced fault is such that substantially decreases the positive sequence voltage from the nominal voltage while the negative sequence voltage increases. Both sequences have to be thoroughly controlled, as discussed in [10], [12].

Nevertheless, grid codes only specify reactive power injection [13], [14]. This makes sense considering that transmission power lines are mainly inductive. When positive sequence reactive currents take negative values, large voltage drops appear, which aids at increasing the voltage at the point of common coupling. In case negative sequence reactive currents take positive values, the negative sequence voltage diminishes. This strategy is likely to become a sub-optimal since transmission lines are not purely inductive. The influence of impedances is mentioned in [12], where the authors express the currents to inject as a function of the voltage and the impedances. A recursive relation between the voltage and the current is found. However, this invalidates the possibility of working with a closed-form expression from where to compute the optimal currents solution. Consequently, the problem has to be presented as an optimization problem, where the objective is to maximize the positive sequence voltage and/or minimize the negative sequence voltage, all this constrained to not surpass the current limitations.

This paper solves precisely such optimization problem. Two other control rules are implemented. One focuses at solving the optimization problem but in addition to the other constraints, it is also restricted to only injecting reactive power. The third control rule follows the implementation of a grid code with its characteristic droop profile. These three options are tested for both balanced and unbalanced fault, where this last category includes line to ground, line to line and double line to ground faults. First, a basic system with a single converter is studied. Then, the analysis is repeated for a system with two converters in order to identify their interaction in saturated states.

The structure of the paper is as follows. Section II formulates the optimization problem and details the methodology employed. Section III presents the results together with the

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correspoding discussion for a single converter case. Section IV shows the same but for a basic power system with two converters. Finally, Section V concludes this work.

II. Problem formulation

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III. Single converter case study

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IV. Two converter case study

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V. Conclusion

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Acknowledgment

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